

INFORMATION REPORT

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CENTRAL INTELLIGENCE AGENCY

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SUBJECT Gyro Development at Novogorsk
near Moscow

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28th February, 1955.

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1. Gyro Development

In 1945 the Soviets acquired from the SIEMENS Works in BERLIN five samples of a gyro which represented the last word in German development. They also at this time acquired Bruno GOLECKI, who had worked on the control mechanism of the V-2, and was very much au fait with current gyro work.

In 1947 GOLECKI was put to work in OKB II in a separate department of which he had complete charge. He had on his staff many Soviet engineers. The five gyros liberated in 1945 were at the department's disposal for further development.

Between 1948 and 1950 GOLECKI took part in many flight tests of gyros when he was taken off gyro development in 1950, they had a good gyro for speeds up to 400 km. per hour. GOLECKI had no doubt that in 1951 the Soviets would be in possession of a gyro capable of operation at 600 km. per hour. It is likely that GOLECKI received his STALIN Prize as a consequence of his gyro work.

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2. Detailed Explanation of the Guidance System

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(ii) Explanation of Signs

- A - effective reflecting surface of target in m^2
- α - deviation angle. The angle formed by the line connecting the mother aircraft and the missile with the beam ($\alpha \ll 90^\circ$)
- Ablage (deviation) - shortest distance between the missile and the beam.
- B - band width
- β - phase of the deviation angle. Angle can be between 0° and 360°
- c - speed of light
- α - phase of deviation angle from target. Angle can be between 0° and 360°
- F_a - $\frac{G_a \cdot \lambda^2}{4 \cdot \pi} =$ effective reception surface of aerial A in m^2
- F_b - $\frac{G_b \cdot \lambda^2}{4 \cdot \pi} =$ effective reception surface of aerial B in m^2
- G_a - amplification of the aerial A in the main reception direction
- G_b - amplification of the aerial B in the main reception direction
- γ - deviation from target. The angle between the axis of the missile (= symmetry axis of the B reception mirror) and the target direction ($\gamma \ll 90^\circ$)
- G_s - amplification of the transmission aerial in the main beam direction
- K - BOLTZMANN's constant
- K·T·B - noise output transmitted to a matched load (JOHNSON noise); T being the absolute temperature of the noise source. Other symbols see above
- Leitstrahl (beam) - straight line between mother aircraft and target
- N_a max - maximum output passed on the A side to the wave guide
- N_e max echo - signal strength per m^2 reaching aerial B
- N_c max - maximum signal power per m received on side A
- N_g - noise output of receiver B with reference to the input end

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- N_0 - transmission output of the transmitter on the mother aircraft in the main beam direction
- N_z - beam power reaching the target per m^2
- Querlage
(lateral position) - angle between longitudinal axis of missile, or a parallel of this axis, and the beam during the first part of the flight.
During the second part of the flight this angle corresponds to the target deviation angle
- r - distance between the missile and the target
- R - distance between the mother aircraft and the target
- Schräglage
(slanting or diagonal position) - angle of the longitudinal axis of the missile with reference to the normal position. The normal position of a missile is when the line between the points of the wings i.e. the lateral axis, is horizontal.
- Strahlungskeule
Empfangskeule
(lobe of radiation or reception) - distribution of the transmitted or received radiation power of a dipole arrangement at rest, depending on the angle
- Symmetrieachse
des Antennenspiegels (symmetry axis of aerial mirror) - axis round which the radiation lobe of the dipole rotates
- T - absolute temperature
- T_z - difference in travelling time between pulse A and pulse B (direct and echo pulse).
- Zielrichtung
(target direction) - direct line connecting the centre of gravity of the missile with the target

(iii) Method

There is no doubt that KUKSENKO and BERIA, [redacted] were very impressed by the flying bomb which was developed during the war by an American firm and was used successfully by the U.S.A. [redacted] The story of the development, construction and application of this weapon was, as is well-known, described in an American technical magazine shortly after the end of the war. The flying bomb had no motor, and, [redacted] its range was something like ten kilometres. The bomb differed from the missile described here by having a magnetron homing device.

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The Russian plan aimed firstly, at increasing the range of this missile and, secondly, at installing devices which would make possible the aiming of the

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weapon at individual important targets in a fleet. They hoped that the pre-selection of such an important individual target could best be effected by a beam radiation from a carrier aircraft equipped with a flexible high power radar installation. This principle made the magnetron homing device in the missile redundant, and created the opportunity for a smaller and lighter electrical steering unit in the missile. The more expensive parts of the system were, therefore, transferred to the mother aircraft which could be used again and again, while the bomb was used only once.

This is one of the advantages of the system chosen by the Russians. Its main disadvantage is probably the fact that the guiding of the missile by the mother aircraft had to be continued until the missile hit the target. If, for instance, the mother aircraft should become involved in a fight with the enemy defence forces, the remote control of the missile could become cut off.

This method was developed for occasions when the enemy would not take any extra measures of interference with the remote control. A very reliable gating device makes the remote control mechanism insensitive to certain kinds of interference.

One must remember here that the above-mentioned American weapon was developed and used against an enemy who was very weak in radio defence for these (particular) wavelengths. The success of the Russian missile described here against an enemy equipped with special radio interference devices, whether a fleet detachment or an individual vessel, may be doubtful.

Another disadvantage of this system is that a mother aircraft with a radar detector could be spotted by an enemy fleet or individual ship at a much greater distance than the aircraft could locate the ship. There is, however, as in the case of many weapons, still the possibility of a surprise attack or an attack against a weak enemy.

The method of obtaining error voltages on the A and B side of the missile is similar to the method frequently used in radar for automatic follow. It is a matter of interest in this case that, in order to achieve the rotation of radiation lobes, e.g. the reception lobe of aerial B with 75 c/s, only the dipole of the aerial, and not the aerial mirror, moves correspondingly in a 75 c/s. rotation.

As is well-known, the time differential coefficients of the first and the second order of the time function of the deviation angle are required as damping parameters for the steering of the missile.

The guiding values which correspond to the differential coefficient, as well as the direct currents would then be transmitted to the autopilot.

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Another proposal of the Russian directors of development aimed at an electrical formation of the time differential coefficients of the lateral position angles too, and at their use in the autopilot for the damping of the later swing. Therefore a special receiver, the so-called "differential unit" was provided on the A side for the purpose of first creating a voltage corresponding to the lateral position, and then differentiating it.

The people who developed the autopilot ignored all these damping values obtained electrically, for as a result of the technical usage in Germany which was familiar to them, it was simpler for them to obtain these parameters in the autopilot by other means.

Development work on the "differential unit" was therefore stopped

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(See "The Organisation of the Laboratories and the Progress of the Task" and Diagrams 6 and 7.)

(iv) Theoretical Principles

With the exception of the autopilot, the theoretical principles of the steering device of the missile are the same as for the development of radar equipment in the 3 cm. band.

The comprehensive standard works in this field were, also of course for the Russian engineers, the publications of the Massachusetts Institute of Technology "Radiation Laboratory Series" Volume 1 to 28, and articles in the relevant technical literature, e.g. Proc.IRE, Electronics, Electrical Engineering, Wireless World, etc. Therefore, please refer to the relevant sources for the theoretical principles underlying the construction of the various units.

In as far as the methods used for some units may be less familiar to an electron engineer, e.g. the methods in the gating unit or in the phase commutator, these are described in somewhat greater detail in the various Sections. A complicated unit, such as the A receiver, is also considered in greater detail. However, it would be found useful, if some calculations about the propagation and reflection of electromagnetic waves were given more fully, even if they are familiar, in order to demonstrate the main properties required from the installation. E.G., it was mentioned in "Method" that the relatively great range in which the missile is supposed to operate presupposes a maximum sensitivity of the echo receiver.

The power ratio on side A is as follows:

Transmission power $N_s = 50 \cdot 10^3 \text{ W}$ (emission),

Distance between mother aircraft and target $R = 10^5 \text{ m}$,

Amplification of the transmitter aerial in the main radiation beam direction

$$G_s = 1000,$$

$$\text{Reception power } N_e \text{ max/m}^2 = \frac{N_s \cdot G_s}{4 \pi R^2} = \frac{50 \cdot 10^3 \cdot 10^3}{12 \cdot 10^{10}} = 4 \cdot 10^{-4} \text{ W/m}^2$$

Amplification of the A aerial $G_a = 40$

$$\text{Effective reception surface } F_a = \frac{G_a \cdot \lambda^2}{4 \cdot \pi} = 3 \cdot 10^{-3} \text{ m}^2$$

Reception power on the A side, transmitted to the wave guide, is

$N_a \text{ max}$ and therefore

$$N_a \text{ max} = \frac{N_s \cdot G_s \cdot G_a \cdot \lambda^2}{(4 \pi)^2 \cdot R^2} = 1.2 \cdot 10^{-6} \text{ W}$$

If the conversion loss of the mixer is assumed to be 10db which corresponds to a coefficient of 10 in the performance/output, a power of $0.12 \cdot 10^{-6} \text{ W}$ is obtained at the input end of the 200 Ohm cable of the A receiver. This amount of power at the grid of the first valve of the A receiver can only be expected if the main radiation direction of the transmission lobe points straight at aerial A. It was assumed that for very considerable deviation angles the reception field strength was reduced to 5% of the maximum field strength, i.e. one twentieth. That would amount to one four-hundredth of the maximum power, i.e. in cases of considerable deviation a power of only $3 \cdot 10^{-10} \text{ W}$ can be counted upon, the distance between the mother aircraft and the target being $R = 10^5 \text{ m}$. Therefore the voltage at the 200 Ohm cable of the A receiver is 250 μV , i.e. a voltage which does not put any special strain on the signal/noise ratio of the I.F. amplifier A.

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The power ratio on side B of the electrical steering mechanism is calculated as follows:

Emitted power of the transmitter on the mother aircraft $N_s = 50 \cdot 10^3 \text{ W}$

Distance between mother aircraft and target $R = 10^5 \text{ m}$

Distance between missile and target $r = 3 \cdot 10^4 \text{ m}$ (maximum)

Amplification of the transmission aerial in the main radiation direction

$$G_s = 1000$$

Radiation power hitting the target, per m^2 $N_z = \frac{N_s \cdot G_s}{4\pi R^2}$

Target cross section A, average for destroyers 10^4 m^2

" " battleships 10^5 m^2

Reception power reaching the B aerial $N_e \text{ max echo/m}^2$

$$N_e \text{ max echo} = \frac{A \cdot N_z}{4\pi r^2} = \frac{A \cdot N_s \cdot G_s}{(4\pi)^2 \cdot R^2 \cdot r^2} \text{ W/m}^2$$

Amplification of the reception aerial $G_b = 600$

Aerial reception cross section B $F_b = \frac{G_b \cdot \lambda^2}{4\pi} \text{ m}^2$

Therefore the echo power transmitted to the wave guide of aerial B is

$$N_e \text{ max echo} = \frac{A \cdot N_s \cdot G_s \cdot G_b \cdot \lambda^2}{(4\pi)^3 \cdot R^2 \cdot r^2} \text{ Watt}$$

If we assume that $A = 10^4 \text{ m}^2$ (destroyer), the approximate $N_e \text{ max echo}$ would be $16 \cdot 10^{-12} \text{ Watt}$, all other values being the same.

In general neither the symmetry axis of the transmitter mirror of the mother aircraft nor the symmetry axis of the B reception mirror of the missile will point directly to the target. If we assume that each of these factors lowers the received pulse power through scanning by 10% of the maximum, the minimum received pulse power would be 1% of the previously calculated maximum power or $16 \cdot 10^{-12} \text{ W}$, i.e. $16 \cdot 10^{-14} \text{ W}$.

The noise output $K \cdot T \cdot B$ for a bandwidth of $B = 2 \text{ Mc/s.}$ is

$$K \cdot T \cdot B = 8 \cdot 10^{-15} \text{ W}$$

The total noise factor of the receiver B could be brought to 12 db, i.e. to a power ratio of 16. Therefore the noise power of the receiver B in regard to the input end of the receiver is

$$N_g = 16 \cdot 8 \cdot 10^{-15} \text{ W}$$

If this noise output is compared with the previously calculated minimum a signal-to-noise ratio of $\frac{16 \cdot 10^{-14}}{16 \cdot 8 \cdot 10^{-15}} = 1.25$ results.

This ratio is valid for the smallest pulse of the 75 c/s. modulated pulse series.

It should be stated once more that the calculation of the signal-to-noise ratio was based on the following assumptions:

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Distance R	10^5 m
Distance r	$3 \cdot 10^4 \text{ m}$
Target echo cross section A	10^4 m^2
Total power loss due to the two scanning processes with 30 and 75 c/s.	100:1

The selector unit is just about able to operate under these reception conditions. Therefore the above-mentioned assumed distances are the permissible maximum distances for the assumed echo cross section. However, the switch-over of the steering from side A to side B is effected only with a considerably greater signal-to-noise ratio which guarantees reliable steering of the missile by the B side.

The question of the uncoupling of the A receiver from the B receiver in the 3 cm. range is of particular importance for the steering mechanism. As mentioned previously, the mixers of both sides, A and B, are fed by the same local oscillator. A signal from the A mixer must have adequate damping during its transmission to the B mixer via the local oscillator. If the direct pulse received by the side A could reach the input end of the I.F. amplifier B with sufficient amplitude, the selector pulse of the selector unit could "set" on this pulse coming from side A and negate the location process.

Therefore it must be specified that the direct A pulses which reach the input end of the I.F. amplifier B in the manner described should disappear in the noise of the B receiver.

As stated before during the consideration of the power ratio on side B, the noise output of the B receiver in regard to the input end of the receiver is $N_B = 16.8 \cdot 10^{-15} \text{ Watt}$. As mentioned during the consideration of the power ratio of side A, the maximum reception power of the A receiver at a distance of 100 km. from the mother aircraft is $N_A \text{ max} = 1.2 \cdot 10^{-6} \text{ Watt}$. Steering of the missile can start at a distance of about 2 km. from the mother aircraft. The reception power of the A side at that distance is about $3 \cdot 10^{-3} \text{ Watt}$. The ratio of the two factors under consideration is therefore $\frac{3 \cdot 10^{-3}}{16.8 \cdot 10^{-15}} = 2.35 \cdot 10^{10}$

which corresponds to a damping requirement of about 104db. This specification must be regarded as a minimum. Another condition is that the direct 3 cm. A pulse coming from side A should suffer a conversion loss of not less than 10db in the B mixer.

(v) Aerials

(a) A Aerial

As stated before that A serial lobe should have a large half-power width and also guarantee reception which is dependent of the polarisation of the received radiation. The amplification of the A aerial is not quite as important as that of the B aerial. After several experiments a horn with an aperture of 16-18 cm. in diameter proved the best solution. The amplification was about 40, and the half-power width about $\pm 15^\circ$. The fluctuation in the amplification of the aerial was not more than $\pm 5\%$, depending on the direction of polarisation.

As already stated the A aerial must be adjustable. More details are given later. For the sake of adjustability the aerial was connected to a flexible silver-plated wave guide.

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(b) B Aerial

The task of the B aerial is to receive the pulses from the mother aircraft as reflected by the target. The requirement was a maximum possible gain which was limited mainly by the fixed maximum diameter.

The receiver lobe of the B aerial must rotate with a frequency of 75 c/s. for the scanning process on the B side. The receiver lobe has a half-power width of about $\pm 2^\circ$ and forms an angle of about 2 to 3° with the symmetry axis of the aerial mirror. The receiver lobe is rotated by means of rotating the dipole of the B aerial. The reception of the aerial actually depends on the polarisation, but the pre-selected targets reflect in an unpolarised manner. With an aerial mirror diameter of about 45 cm a gain of 600 could be achieved.

The design of the mirror and the rotating dipole, as well as the coupling of the wave guide with a rectangular cross section to the cylindrical wave guide of the aerial is shown in Diagram 9. This diagram also shows the mechanics of the dipole drive by means of a motor generator.

The aerials described here were designed and tested mainly by Serge LISITSIN, a Russian colleague. Later aerial development was taken away from Department I (Electrical Steering Section), and from that time onwards carried out by a Russian development section. (See Organisation Scheme, Diagram 7).

(vi) Wave Guides

Wave guides, as well as mixers and aerials in the entire electrical steering installation, were made of sheet brass and were silver-plated and hard-soldered.

The Russian standard sized wave guides were used. In this installation they were of type WR 90 (RMA Designation) for a wave length of about 3.16 cm. The dimensions are shown in Diagram 10.

Flexible silver-plated wave guides were used for connecting the adjustable A aerial, and also as short connecting joints between parts of the installation.

Both the rigid and the flexible wave guides had the parameters quoted for this type in the Anglo Saxon technical literature. Standard flanges too, were used for connecting wave guides to each other.

In order to avoid the burning out of the crystal in the A mixer shortly after the release of the missile from the mother aircraft the wave guide to this mixer was provided with attenuation links which were automatically released after a certain flying time, by a small motor. The form of the attenuation links is shown on Diagram 11. They consisted of strips of Novotex covered with graphite.

Provision was made for protecting the wave guide system from moisture.

(vii) Mixer

The mixers on both sides, A and B, of the electrical steering device were in the form of simple differential mixers with a magic T (Magic T Balanced Mixer). This type of mixer was chosen, as is usual in such cases, because of the high requirements of the B echo receiver.

This type of mixer, as is well-known, eliminates for all practical purposes the influence of the noise of the local oscillator on the noise of the receiver as a whole. Besides, if a pair of crystals with as equal

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properties as possible (equal conversion loss, noise temperature and impedance at 3 cm) is used, the contribution of this two-crystal mixer to the total noise is no greater than that of a single crystal mixer.

Russian silicon crystals were available for the installation. In order to utilize the advantages of a balanced mixer two crystals with almost equal properties were chosen for each mixer. Such a selection was possible among the Russian crystals without too many difficulties.

The coupling of the 3 cm. signal, the local oscillator and the input ends of the I.F. amplifiers to the A and B mixers did not differ from the detailed descriptions of this arrangement found in technical literature. The development engineers derived the most important information about mixer problems from POUND's "Microwave Mixers" in the "Radiation Laboratory Series" of the Massachusetts Institute of Technology (Volume 16). Chapter 6 of this volume describes the mixers used in the steering device in detail.

(viii) Local Oscillator

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As stated previously, the local oscillator had to feed two mixers, A and B, through a magic T.

Section "Receiver A" describes how the klystron receives its regulating voltage for the automatic frequency adjustment. The range of control could be brought to the figure of ± 40 Mc/s. which was considered adequate for adjustment to the frequency of the magnetron transmitter on the mother aircraft.

The power supply unit supplied to the reflex klystron in the local oscillator regulated operating voltages for the anode and the repeller electrodes.

(ix) Automatic Frequency Regulation

The regulating voltage for the automatic frequency adjustment of the klystron local oscillator is supplied by a diode transitron circuit in the A receiver. It transpired that the circuit described by R. V. POUND and E. DURAND in the book "Microwave Mixers" (Sec. 7.13, p.326) could be used almost without modification, but for the sake of completeness it is shown in Diagram 12.

The diode transitron circuit is fed as usual by a discriminator which is also located in the A receiver and which is described later.

The range within which automatic frequency adjustment operated was about ± 40 Mc/s.

(x) Automatic Aerial Adjustment

As described in "Resume of the Project", and in more detail elsewhere, it is essential to rotate the A aerial additionally in accordance with the occurring lateral or inclined sloping position angles. This additional rotation is effected round two axes, one of which coincides with the missile's longitudinal axis and the other is parallel to the rudder axis.

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Adjustment is effected with two small motors built in into the A aerial, one for each axis. These motors receive their operative currents from the autopilot in accordance with the existing angles, and report their rotation angles back to the autopilot through slide-wire resistances which are also operated by the same motors. Telegraphic relays T rls 65 of SIEMENS and HALSKE, as described later, were used for this automatic operation.

The A aerial turned only up to a certain maximum value of the adjustment angle. When this maximum angle was reached the operating current of the motors was switched off.

As far as design and mechanical construction were concerned, the A aeriels and their automatic adjustment mechanism were works of art. Their designer was O. KALBITZ, and they were constructed and adjusted by BLESCHKE, SCHILLER and KUHFIELD.

(x1) Receiver A

As mentioned in "Resume of the Project", the receiver A had four functions:

1. the creation of the 30 c/s. error voltage,
2. the production of a trigger pulse for the selector circuit,
3. the production of a regulation voltage for the automatic frequency adjustment of the klystron local oscillator.
4. the supply of the 30 c/s. reference phase.

Two of these functions, the production of the trigger pulse for the selector circuit and of the regulation voltage for the local oscillator are required for the entire trip right up to the target. The 30 c/s. error voltage and the 30 c/s. reference voltage are required for the first part of the trip only. The schematic block Diagram 8 shows the manner in which the receiver A transmits to the other units the four above-mentioned voltages which it produces.

The A receiver unit comprises:

- a four-stage 40 Mc/s I.F. amplifier with automatic amplification regulation,
- a demodulator for the 30 c/s. error voltage,
- a blocking generator, followed by a demodulator for the time demodulation of pulses,
- a discriminator, followed by a diode transitron circuit for automatic frequency adjustment of the local oscillator.

These components are shown individually in the schematic Diagram 13 of the A receiver.

As already described, the A mixer operates on the I.F. amplifier of the A receiver via a concentric cable with a characteristic impedance $Z = 200 \text{ Ohm}$. The input circuit of the A receiver is shown in Diagram 14. The cable ends in a transformer tuned on the secondary side. The I.F. amplifier is constructed in the usual way of four equal stages, coupled with band filters with 6AG5 valves. Later it was to be used with 6AK5 valves. The bandwidth was $B = 2 \text{ Mc/s}$.

The demodulator for the 30 c/s. error voltage started with a video detector in the form of an anode rectifier. In order to obtain the 30 c/s. amplitude modulation of the received pulse series there was a video amplifier, and then a detector which took off the 30 c/s. modulation. The demodulator achieved an output voltage of about $1 V_{\text{eff}}$ and transmitted this level through the commutator stage to the high-resistance input end of the phase commutators.

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The blocking generator of the A receiver required a trigger pulse which must be certain to start the generator even when the missile is at a great distance from the mother aircraft, or if the modulation is at its lowest depth. This trigger pulse was obtained by amplifying the video pulse from the anode detector of the demodulator for the 30 c/s. error voltage. The blocking generator emitted a negative trigger pulse, the so-called A pulse, of 50 V to the selector unit. The same pulse was used to create a fixed or reference phase of 30 c/s. in the demodulator for time demodulation. The demodulator supplied a voltage of about 0.1 V_{eff} to the high-resistance input end of a 30 c/s. amplifier in the commutator stage which emitted two voltages in quadrature. This amplifier will be referred to as the "two-phase amplifier" from now on.

A discriminator of the FOSTER-SEELEY type, with preceding limiter, followed by a STRANDEERG detector, was connected to the 40 Mc/s. amplifier. This discriminator activated the usual type of diode transition regulation circuit which supplied the regulating voltage for additional frequency adjustment to the repeller electrode of the reflex klystron.

The A receiver too differed fundamentally from BERIA's proposals. Some details of its design are of interest.

Diagram 15 shows the coil frame for the coils of the band filter, the limiter circuits and the discriminator. These coil frames were made of Nowotex in the models, but in mass production a pressed/stamped component was to be used. The coils were balanced in the usual way by means of a copper pin.

Diagram 16 shows a bypass collecting condenser which was very useful for the design and construction of I.F. amplifiers and their electrical performance. The condenser was built up simply with layers of copper foil and mica discs as the diagram shows quite clearly.

The circuit in Diagram 14 shows an example of the application of the condenser in an I.F. amplifier stage. The bypass condensers C₁, C₂, C₃, C₄ and C₅ are combined into a collective condenser.

Diagram 17 shows a cross section of the A receiver. The receiver frame is cast iron. On both sides of the cast iron frame double L-shaped aluminium sheet angles are fixed. This framework is compact and electrically advantageous. The valve stages of the receiver which are less sensitive in regard to their physical arrangement, e.g. demodulators and video stages, fit inside the cast frame.

(xii) Receiver B

As stated in "Theoretical Principles" the noise factor of receiver B, in contrast to receiver A, should be as small as possible. The noise factor of the input stage of the 40 Mc/s. I.F. amplifier is very low. This stage is made up of two 6AK5 valves operated in a triode connection/circuit. The first stage has an earthed cathode, the second an earthed grid. The circuit is well-known and frequently described in technical literature, e.g. in the book "Microwave Receivers" by van VOORHIS (1948), Sec.4.13, p.119. However, for the sake of completeness the circuit is shown in Diagram 18.

The input circuit is followed by five graded I.F. amplifier stages with 6AG5 type valve or the Russian copy of this type - 6A5. The I.F. amplifier amplifies the I.F. pulses to the degree required for rectification in the video rectifier. The video pulse is transmitted to the selector.

The overall bandwidth of the B amplifier was $B = 2$ Mc/s. The time constant of the automatic amplification regulation was chosen in such a way that no regulation of the 75 c/s. amplitude modulation of the pulse

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occurs. The 75 c/s. demodulation is carried out in the selector unit after the selection of the video pulses. No provision was made for anti-clutter circuits in the five models of the steering device.

The construction of the amplifier is shown in Diagram 19. The space-saving, layered mica condensers were used in receiver B too, and made the design compact and stable. The condensers were described previously and are shown in Diagram 16.

Receiver B too differed in its electrical and mechanical structure from the receiver shown in BERIA's work.

(xiii) Selector Unit

It is the task of the selector unit to select from the various signals which the B aerial is capable of picking up those pulses which are emitted from the pulse transmitter of the mother aircraft and reflected from the chosen target.

The selector unit receives the B pulse ("target pulse" or "echo pulse") through the B aerial, the B mixer and the B I.F. amplifier and its video component. It receives the A trigger pulse through the A receiver and its video component followed by the blocking oscillator.

The echo pulse which is reflected from the target has the same pulse recurrence frequency and the same time modulation as the direct A pulse. The selector unit has to make these two pulses coincide.

The B pulse, as compared with the A pulse, is displaced in time by:

$$T_z = \frac{2 \cdot r}{c}$$

"r" being the distance of the missile from the target and "c" the speed of light. Therefore it is necessary to displace the A pulse in time so that synchronisation can be achieved.

Before synchronisation takes place the echo pulse must be "found." For this purpose the A pulse is periodically delayed in a rhythm of e.g. two seconds, i.e. it must travel up and down in the "search area" which can e.g. be chosen in such a way that the selection process does not start until 30 km. before the target.

After effecting synchronisation, i.e. after the B pulse is "found", the time displacement of the A pulse must be altered automatically, because the distance "r" changes.

After "finding" the B pulse the selector unit has a further task, viz., to supply from the selected pulses the continuous voltage for the automatic amplification regulation of the B I.F. amplifier.

The continuous voltage is also used as switching voltage for the so-called commutator switch-over stage. Therefore, when the regulating continuous voltage has reached a certain degree, it switches, by means of this unit, the electrical steering of the missile from receiver A to receiver B. This switch-over occurs only when a reliable reception by side B, and therefore reliable steering by receiver B, is guaranteed.

The selector unit also effects the 75 c/s. demodulation of the selected pulses. The 75 c/s. error voltage is supplied via the commutator switch-over stage to the input ends of the phase commutators.

Diagram 20 is a schematic diagram of the selector unit. The time-delay multivibrator is started by the A pulse. The rear edge of the pulse produced by the multivibrator starts the blocking oscillator which produces a so-called selector pulse for the "synchronisation detector". The latter also receives the B pulse through a video amplifier and the delay cable.

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During the search process the rear edge of the pulse from the time delay multivibrator is displaced in time by a saw-tooth voltage of e.g. 0.5 c/s. produced by the transitron stage. As soon as synchronisation between the A pulse and the B pulse is established, the synchronisation detector produces a continuous voltage which stops the saw-tooth voltage production in the transitron stage, and therefore stops the search process, and transforms the transitron stage into a D.C. amplifier.

The continuous voltage now moves the rear edge of the pulse from the multivibrator up in accordance with the time difference T_x , and synchronisation takes place. In accordance with delay time T_x , and the selected "regulation transformation", both pulses, the selector pulse I_0 and the B pulse I_1 , delayed by the delay cable and transmitted to the grid of the synchronisation detector, coincide. The synchronisation of the two pulses can be arranged as desired by selecting the right values of the transmission time cable.

Diagrams 21, a and b, show two pulse positions. Diagram 21.a shows the position of the pulses shortly after the stopping of the search process. Diagram 21.b shows the position of the pulses immediately before the time difference becomes $T_x = 0$.

The synchronisation demodulator transmits the synchronising pulses (and no others) to the input ends of both output stages of the selector unit: the 75 c/s. demodulator obtains the error voltage of side B, and the regulating voltage stage produces the continuous voltage for the automatic amplification regulation of the B receiver.

As shown in "Resume of the Project" the echo reception may have an undesired amplitude modulation of 30 c/s. Therefore the 75 c/s demodulator of the selector unit has a 75 c/s filter which ensures a suppression of the 30 c/s. voltage. Besides, the phase commutators, when operated by side B with 75 c/s, react only very slightly to a 30 c/s. interference modulation.

The anode current for the selector unit is supplied by an electronically regulated source in the power unit.

The selector circuit reacted reliably to three pulses of a series, it was extraordinarily insensitive to interference and stable in operation.

The selector unit design was completely different from the circuit proposed in BERIA's draft which was copied directly from an American type (circuit with thyratrons).

(xiv) Switch-over Stage

The switch-over stage combined the two-phase amplifier for the reference phase of 30 c/s. and the switch-over device, a flip-flop circuit. As mentioned before, the switching over from the A side to the B side is carried out as soon as the regulating voltage of the automatic amplification regulation of the B receiver reaches a certain value. The regulating voltage supplied by the selector unit must be large enough, during the switch-over, to guarantee reliable reception on the B side. Switching back to the A side occurs only if the voltage falls considerably below the switching value of the first switch-over.

The flip-flop circuit activated a relay which had contact switches for the following functions:

1. switch-over from the 30 c/s. reference phase to the 75 c/s. reference phase,
2. switch-over from the 30 c/s. error voltage to the 75 c/s. error voltage,

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3. the autopilot receives a signal about the completed switch-over by means of a commutator switch. (see also Diagram 8).

The two-phase amplifier for 30 c/s. had at its input end a phase-shift link for a 90° phase shift. This was followed by two amplifier channels each of which had a power output of about 0.3 W for the supply of the rotating-field phase shift.

(xv) Phase Commutator

As already stated in "Resume of the Project", two 30 c/s. voltages (as well as two 75 c/s. voltages) were produced by the steering device on the missile: one of these voltages having a fixed phase, or, the reference phase, and the other voltage a changeable phase, the phase and amplitude of which depends on the position of the missile in space. The phase difference between these two voltages is converted into a D.C. value in the phase commutator.

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Diagram 22 shows the principle of such a phase commutator.

The amplified 30 c/s voltage of the changeable phase, the so-called error voltage, is transmitted to the transformer "U" which has two equal windings, I and II, on the secondary side. A polarised relay with a neutral position in the centre and two operative positions of the armature "R" places line "a" to winding I during one half of the period, and to winding II during the second half of the period. The central, common point of the second differential winding adjoins line "b". The winding of the relay, i.e. the operative coil of the armature, is fed by the reference phase.

A direct current which, as will be shown, depends on the phase relation of the two voltages and the amplitude of the error voltage, passes along lines "a" and "b" through the load resistance " R_a ".

Diagrams 23 a, b, c and d show the resultant curves for various phase differences of the reference phase and the phase of the error voltage. The times of the armature swing-over are shown in the diagram by means of vertical broken lines.

Diagram 23.a shows phase difference 0° which results in the maximum positive D.C. Diagram 23.b shows a phase difference of 90° , D.C. equalling 0. Diagram 23.c shows a phase difference of 180° , with a maximum negative D.C. Finally, Diagram 23.d shows a phase difference of 270° , and the D.C. value is zero.

Diagrams 23.a, b, c and d show that the direct currents supplied by the phase commutator have superimposed upper harmonics of the 30 c/s. error voltage. These harmonics are filtered out by a low pass filter, (see Diagram 22).

An analysis of the switching process shows that the D.C. from the phase commutator changes strictly sinusoidally with the phase difference of the reference phase and the phase of the error voltage, as shown in Diagram 24. Of course, the amplitude of the error voltage is assumed to be fixed.

If two phase commutators which are identical, but the reference phases of which are displaced at 90° in relation to each other, are used, a commutator state results, the direct currents of which represent the coordinates of the missile in space in accordance with Diagrams 3 and 5. There is then an X commutator and a Y commutator. The X commutator e.g. produces direct currents only when the missile is not on the Y axis, and vice versa.

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It should be stated here that the low pass filter behind the phase commutators is designed to have a minimum time constant (short transmission time.) However, this is naturally limited by the law that the time constant depends on the limit frequency, viz. it is in inverse ratio. The autopilot allowed for a fluctuation of the D.C. up to 10%.

The dependence of the D.C. on the amplitude of the error voltage during constant phase difference is of interest. Diagram 25 shows this dependence up to 15mA D.C. through a resistance of 1000 Ohm. In the designed commutators it was practically linear.

The transformer "U" shown in Diagram 22 is the output transformer of a push-pull terminal output stage with a 6J6 valve. The prestage is also equipped with the 6J6. The power output stage emits several hundred mW.

The use of relays in phase commutators results in degrees of effectiveness which are practically the same as the theoretically possible degrees of effectiveness of transforming A.C. into D.C.

As mentioned earlier, a so-called polarised relay with the neutral position in the centre and two operative positions of the armature was used. When excited, one of the two contacts was closed, depending on the direction of the current in the winding. The telegraph relays T rls 65 made by the firm of SIEMENS and HALSKE were used, as they were available, in their original wrappings, in large quantities in the so-called trophy stocks. The operational output of these relays was about 50 mW. By special adjustment it was possible to attain even lower values. These relays were also used in the autopilot.

The Russians copied this relay, just like to many other units, in Leningrad.

Similar to all the other units, the phase commutators too differed from the design given in BERIA's work, where a ring modulator was to act as switch. Diagram 26 shows the principle of that circuit. The effectiveness of that switch arrangement is much lower, due to the resistance of the rectifiers in the pass direction.

As is well-known, valve circuits too are used for such phase commutators in radar equipment. In future the use of transistors may be advantageous.

As far as structural design of the phase commutators is concerned, the X commutator and the Y commutator are placed together on a cast iron frame. The commutator unit was constructed, like all the other units, so as to be slipped into place (see "Design and Structure of the Models").

(xvi) Rotating Field Phase Displacement Device and 75 c/s. Aerial Motor

(a) The phase displacement device developed under the name of "rotating field phase displacement device" was a two-phase device. There are two separate windings on its laminated stator and these produce two phase-displaced fields, at 90° in relation to each other, in the adjustable armature. These two stator windings are fed with the two voltages, with a phase displacement of 90° in relation to each other, from the two-phase amplifier, or by the two voltages, with a phase displacement of 90° in relation to each other, from the 75 c/s. motor. On the armature there were also two windings at right angles to each other and in which two voltages, with a phase displacement of 90° in relation to

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each other, were induced. The armature could be turned between 0° and 360° . On the armature axle there were two switches, one for each phase. A precision of less than $\pm 1^\circ$ was achieved in the coinciding of armature turning angle and the phase of the voltage output.

The output taken from the phase displacement device was about 70mW per phase (12 V on 2000 Ohm impedance of the polarised relays T rls 65).

The dimensions of the phase displacement device were: diameter about 50 mm., length about 70 mm. The first samples of these phase displacement devices made by modifying rotating field instruments of appropriate dimensions from trophy stocks.

(b) The 75 c/s. aerial motor was the usual type of German centrifugally regulated small motor with which the generator for the 75 c/s. reference phases was directly coupled. The aerial motor had an output of about 4 W. The generator coupled to it supplied the rotating field phase displacement device with reference phases of about 200mW.

The aerial motor had a diameter of about 50 mm. and, together with the generator, was 120 mm. long. The number of r.p.s. revolutions was kept constant with an accuracy of about $\pm 1\%$ by a centrifugal governor.

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PART IV - LIST OF APPENDICES AND ANNEXES

Appendices - Nil

- Annex "A" - Organisation plan to July, 1948.
 " "B" - " " July 1948 - February 1950.
 " "C" - Overall block diagram.
 " "D" - Sketch of B Aerial.
 " "E" - Attenuation unit.
 " "F" - Transistor regulator circuit.
 " "G" - Block diagram of A. Rx.
 " "H" - (i) Input circuit of A. Rx.
 (ii) Sketch of H.F. coils.
 " "I" - Section through A. Rx.
 " "J" - Input circuit of B. Rx.
 " "K" - Section through B. Rx.
 " "L" - Block diagram of selector (gate).
 " "M" - Pulse forms in selector.
 " "N" - Basic circuit of phase commutators.
 " "O" - Waveforms in phase commutator.
 " "P" - (i) D.C. as function of phase difference.
 (ii) D.C. as function of Input amplitude.
 " "Q" - Phase commutator with ring modulator.

FC/AM

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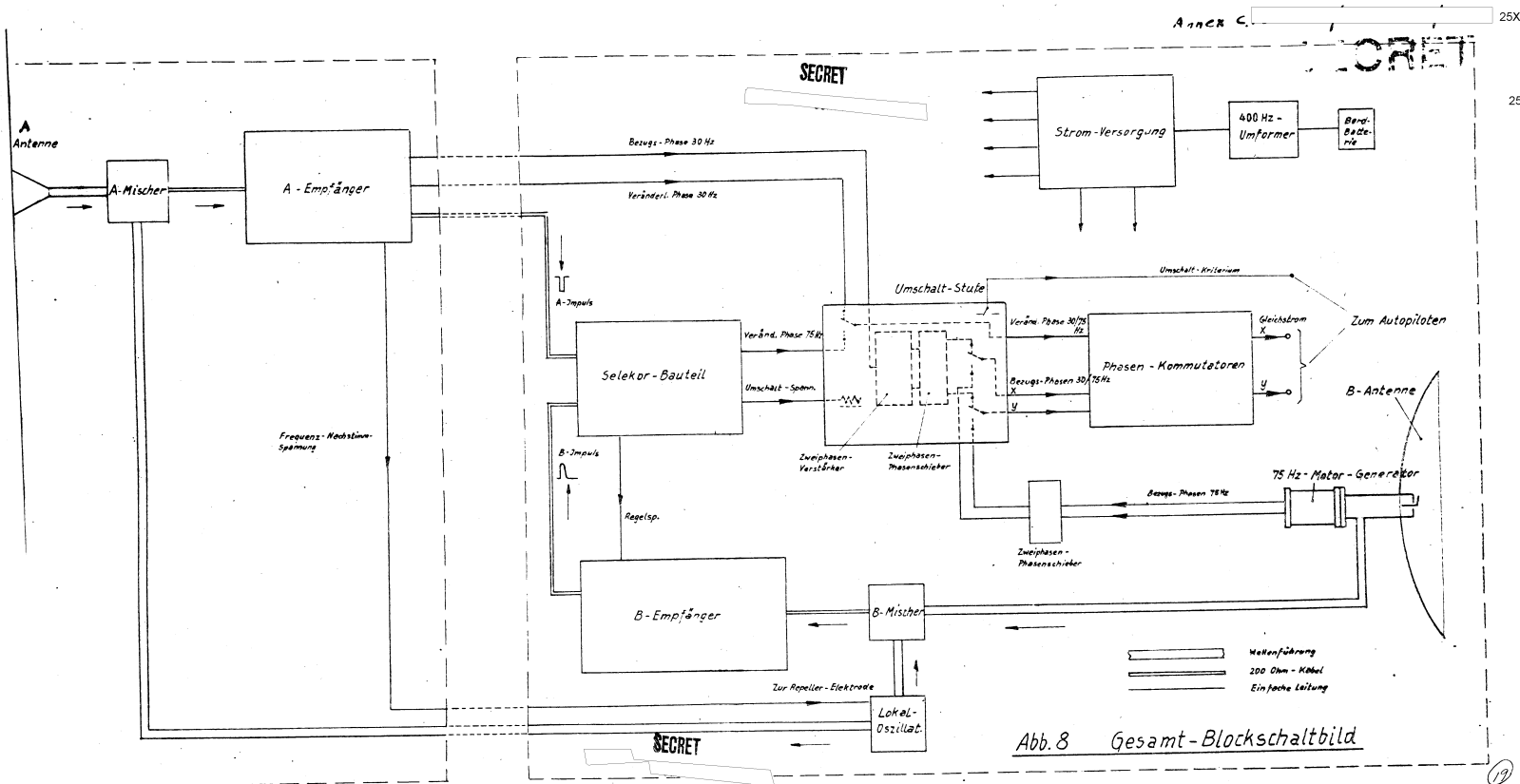


Abb. 6 Organisations-Plan, gültig bis Juli 48

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Abb. 7 Organisations-Plan, gültig von Juli 48 bis Dez 49 / Febr. 50



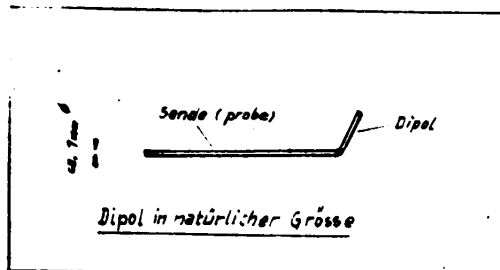
Annex D.

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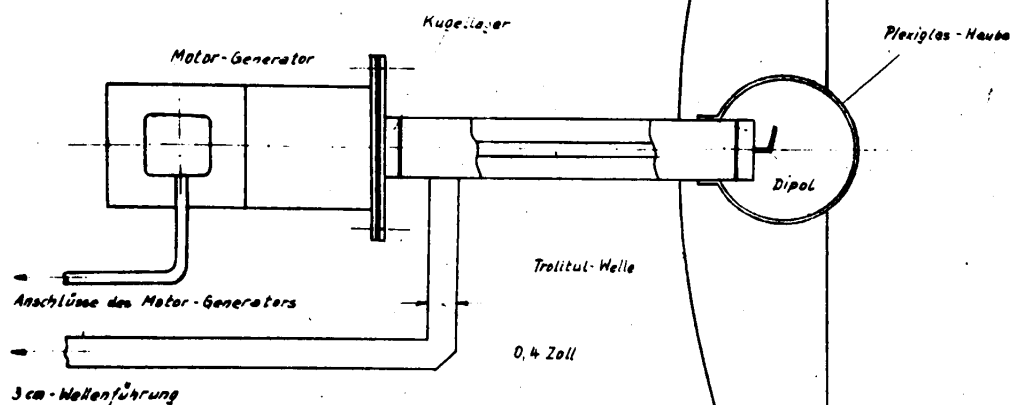
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Antennen-Spiegel



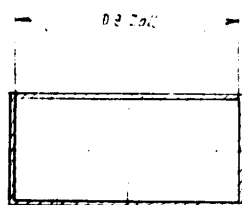
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Abb. B - Antenne

Annex E

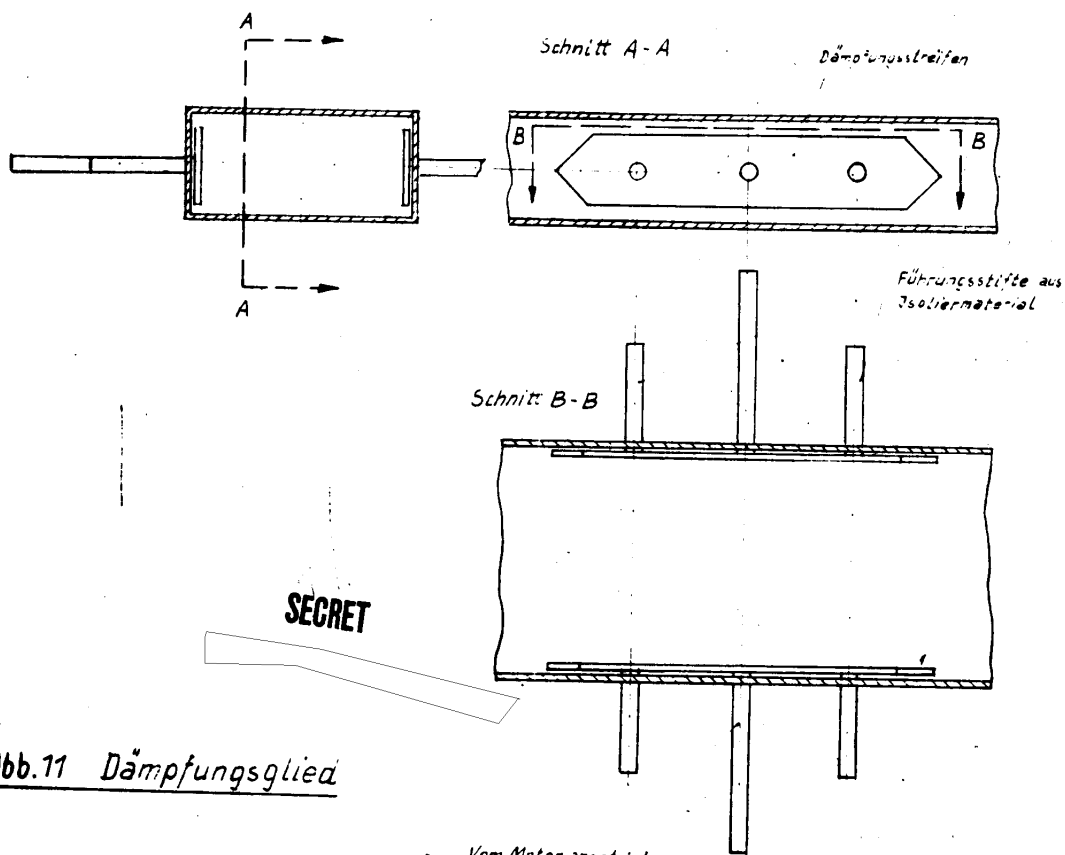
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Abb. 10 Wellenführung WR 90



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Abb. 11 Dämpfungsglied

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Annex F.

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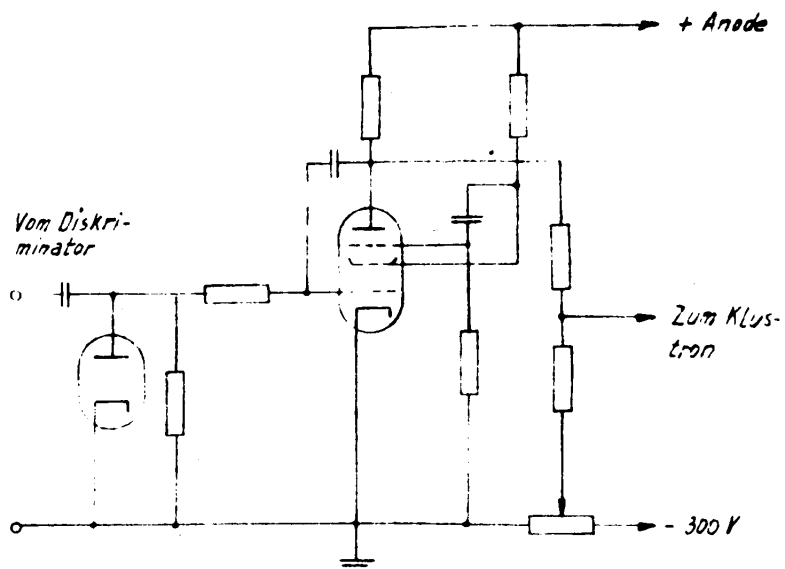


Abb. 12 Dioden-Transitron - Regelschaltung

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Annex G.

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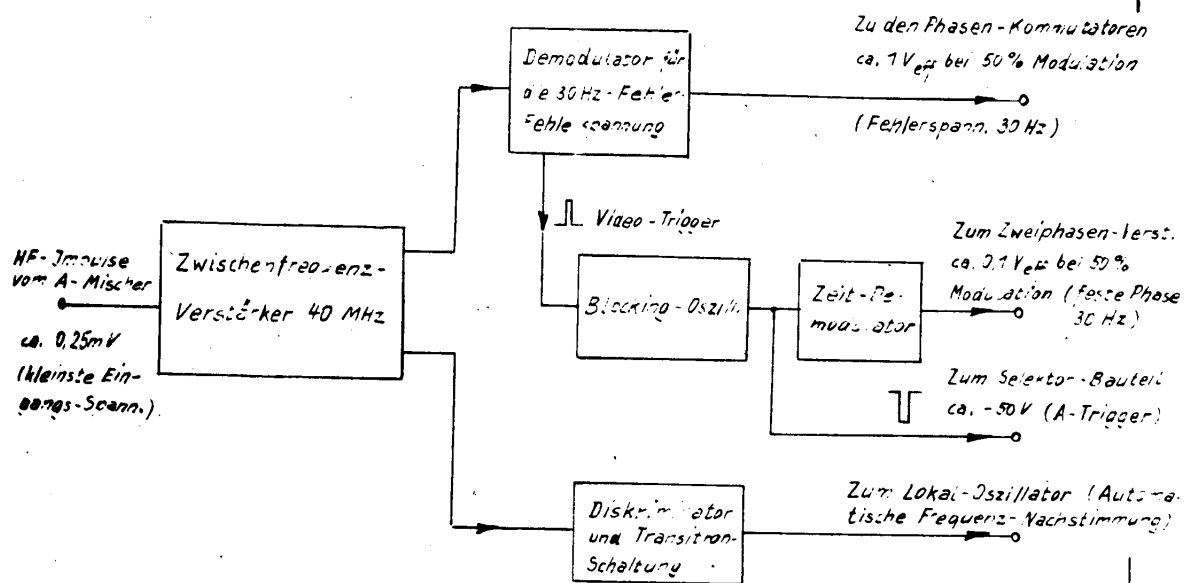


Abb. 13 Blockschaltbild des A-Empfängers

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Annex H.

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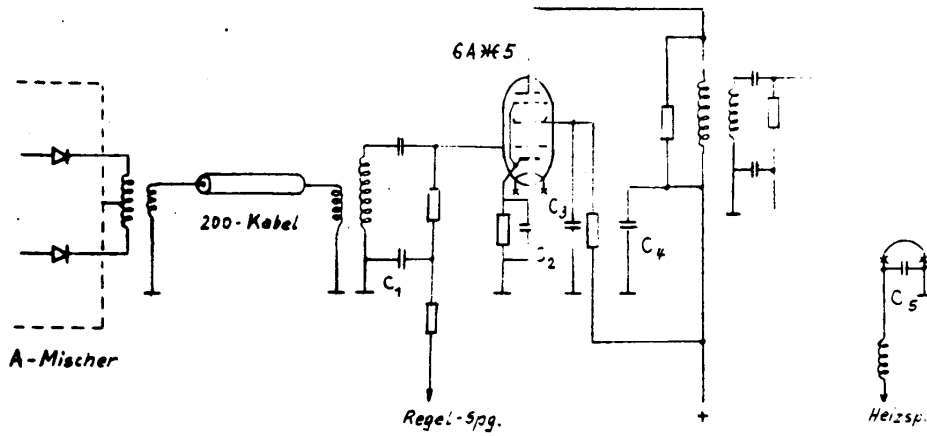


Abb. 14 Eingangsschaltung des A-Empfängers

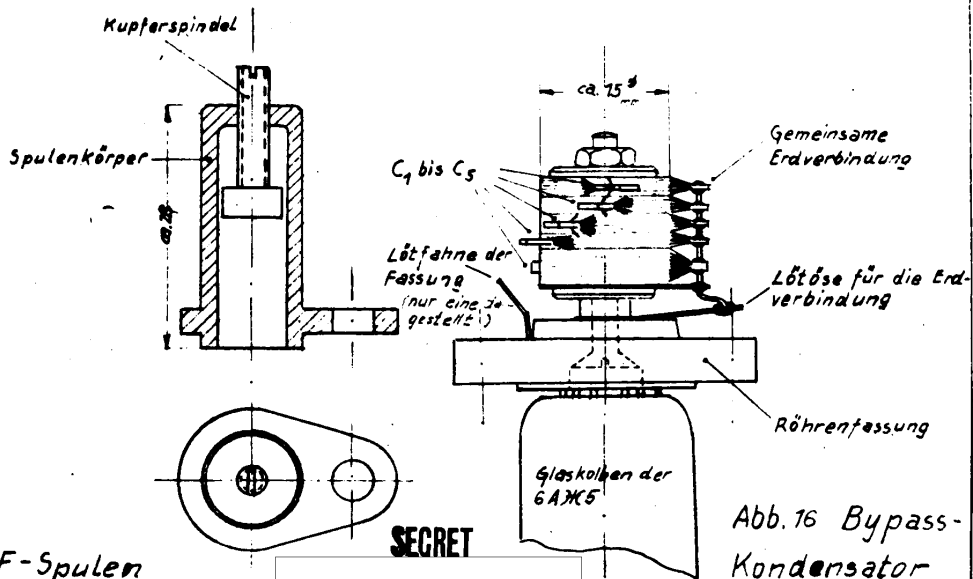


Abb. 15 HF-Spulen

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Abb. 16 Bypass-Kondensator

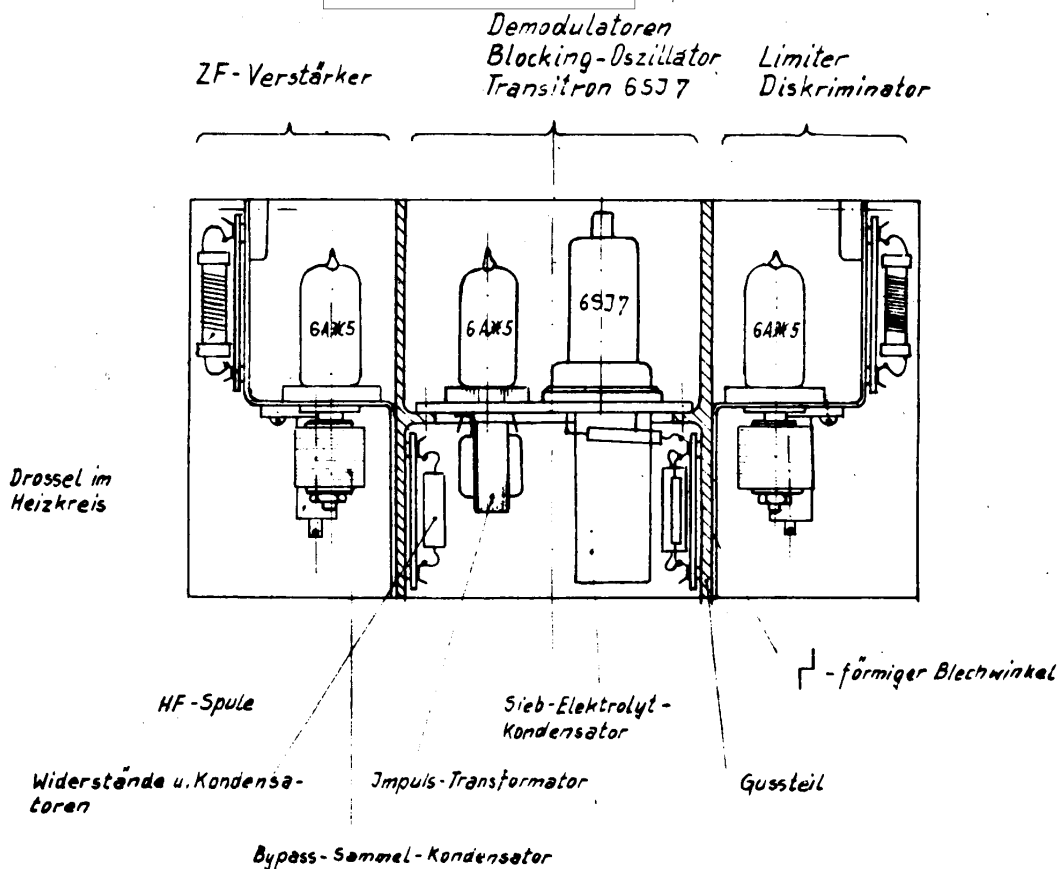
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Annex I

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Unwesentliche Details sind nicht gezeichnet!

Abb. 17 Schnitt durch den A-Empfänger

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Annex J.

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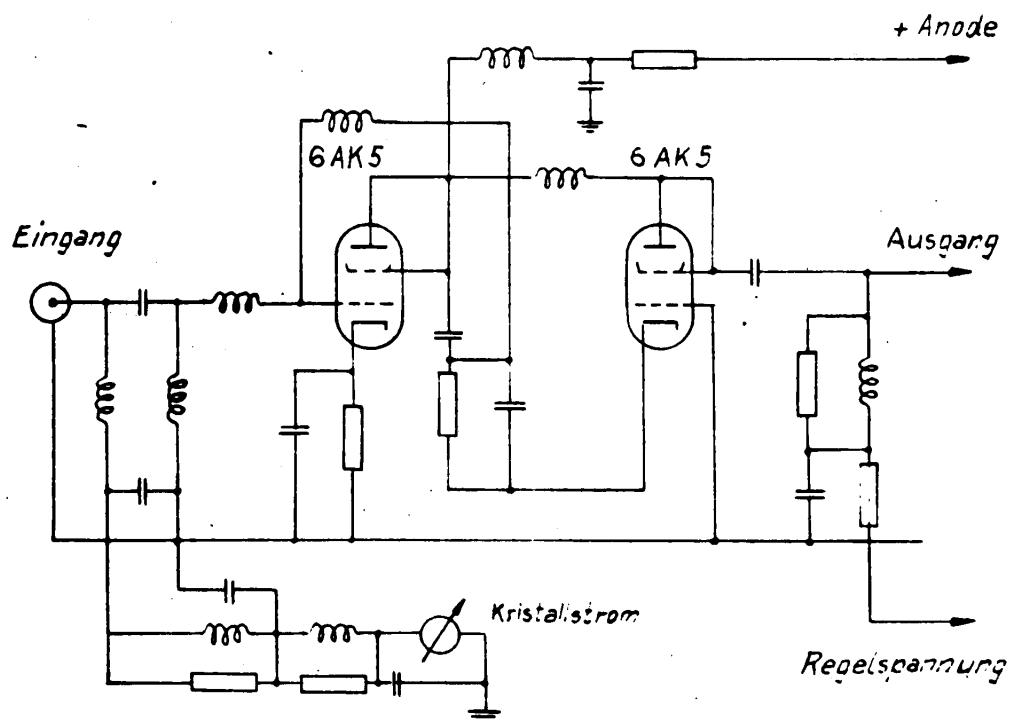


Abb. 18 Eingangsschaltung des B-Empfängers

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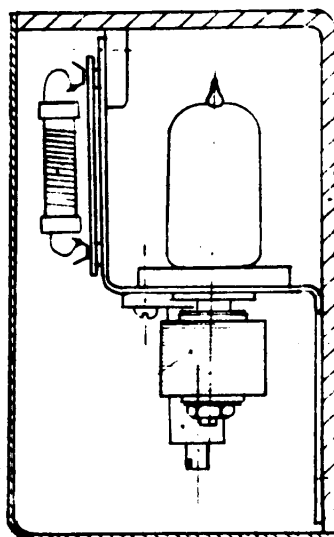
Annex A

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*Netzrosseln, Entkopplungs-
Widerstände u.s.w.*



*Aluminium-
Haube*

*Bypass-
Sammel-Kondens.*

Gussteil

L-förmiger Blechwinke!

HF-Spulen

Unwesentliche Details sind nicht gezeichnet!

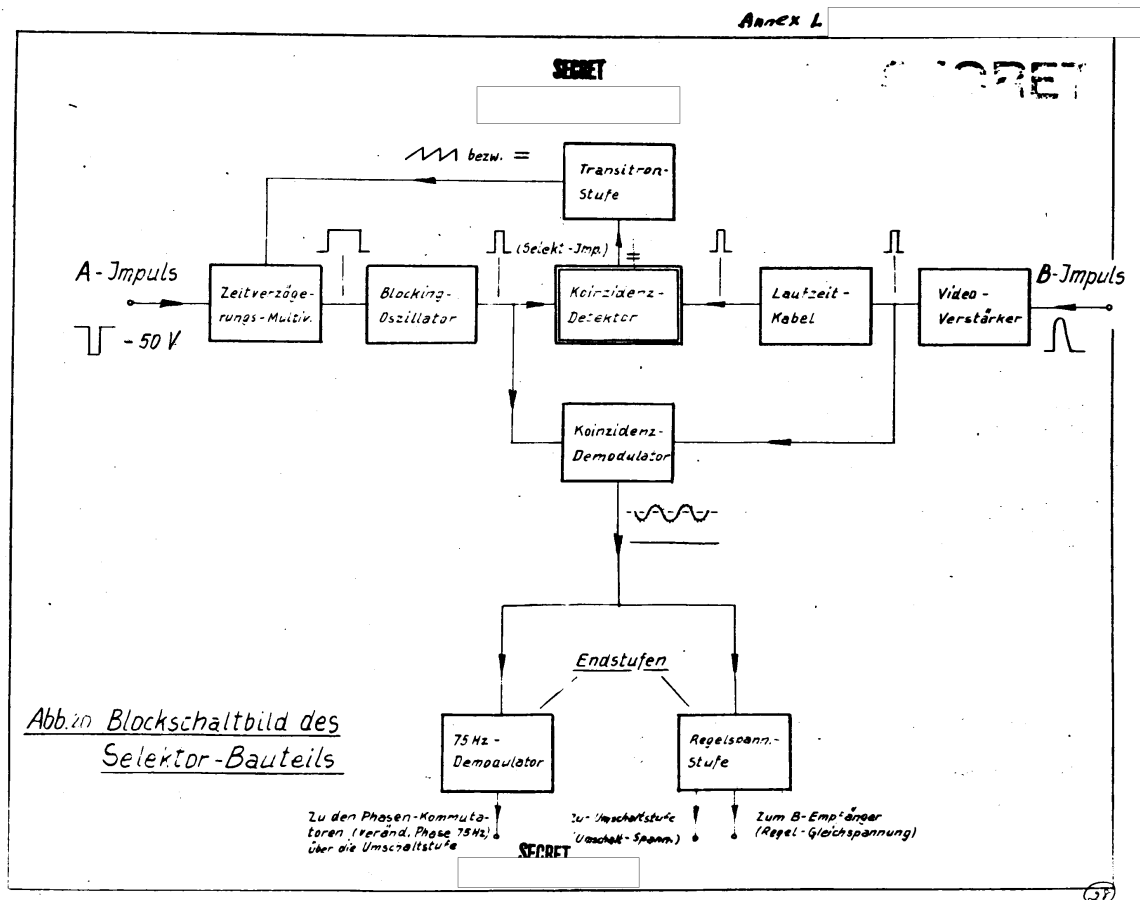
Abb. 19 Schnitt durch den B-Empfänger

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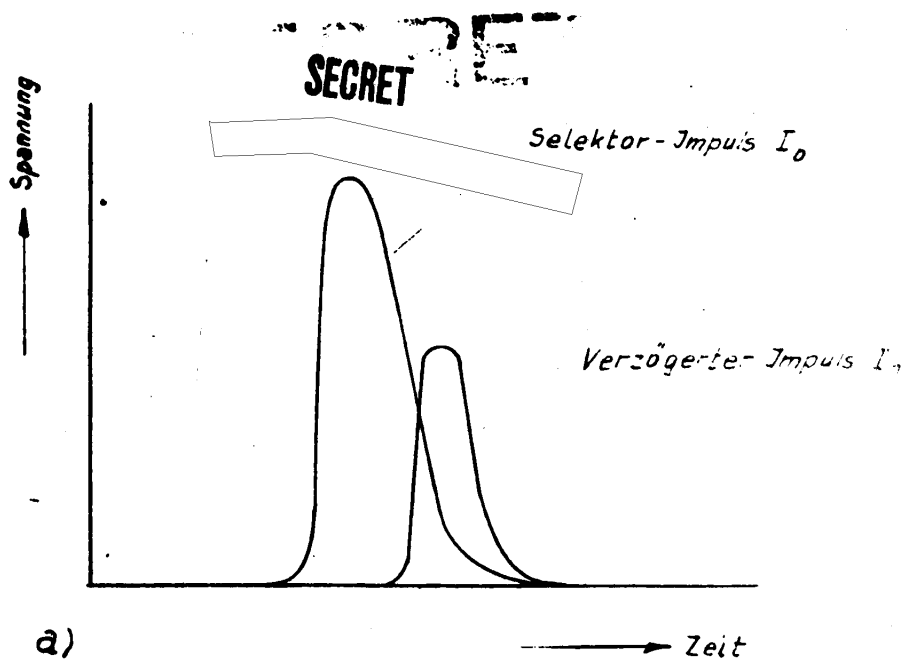
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ANCK M.

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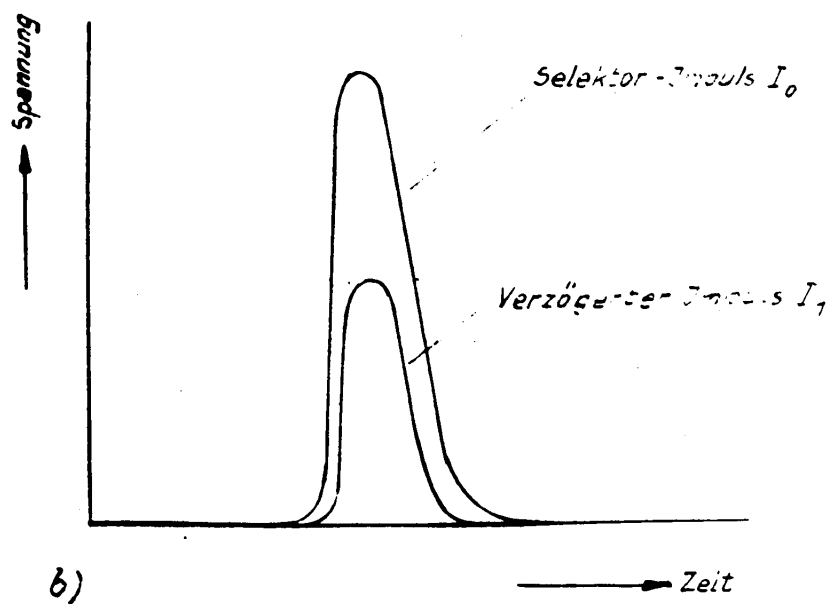


Abb 21 Impulse im Selektor-Bauteil
(s. Text)

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Annex N

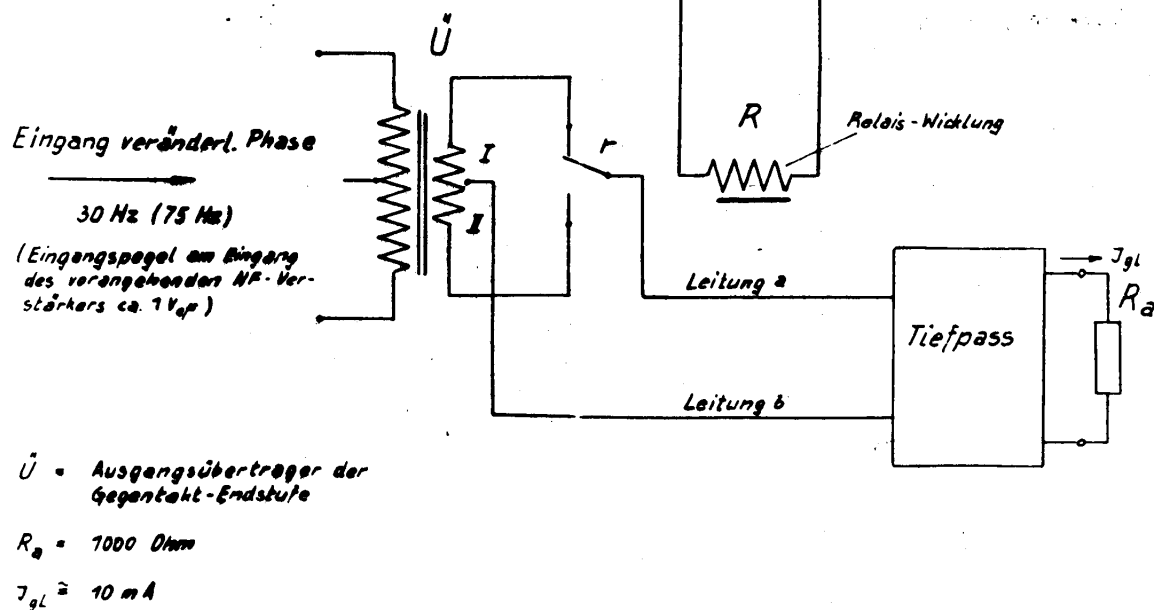
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Eingang feste Phase 30 Hz (75 Hz)

Abb.22 Prinzipschaltbild des Phasen-Kommutators

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(30) E

Anex O

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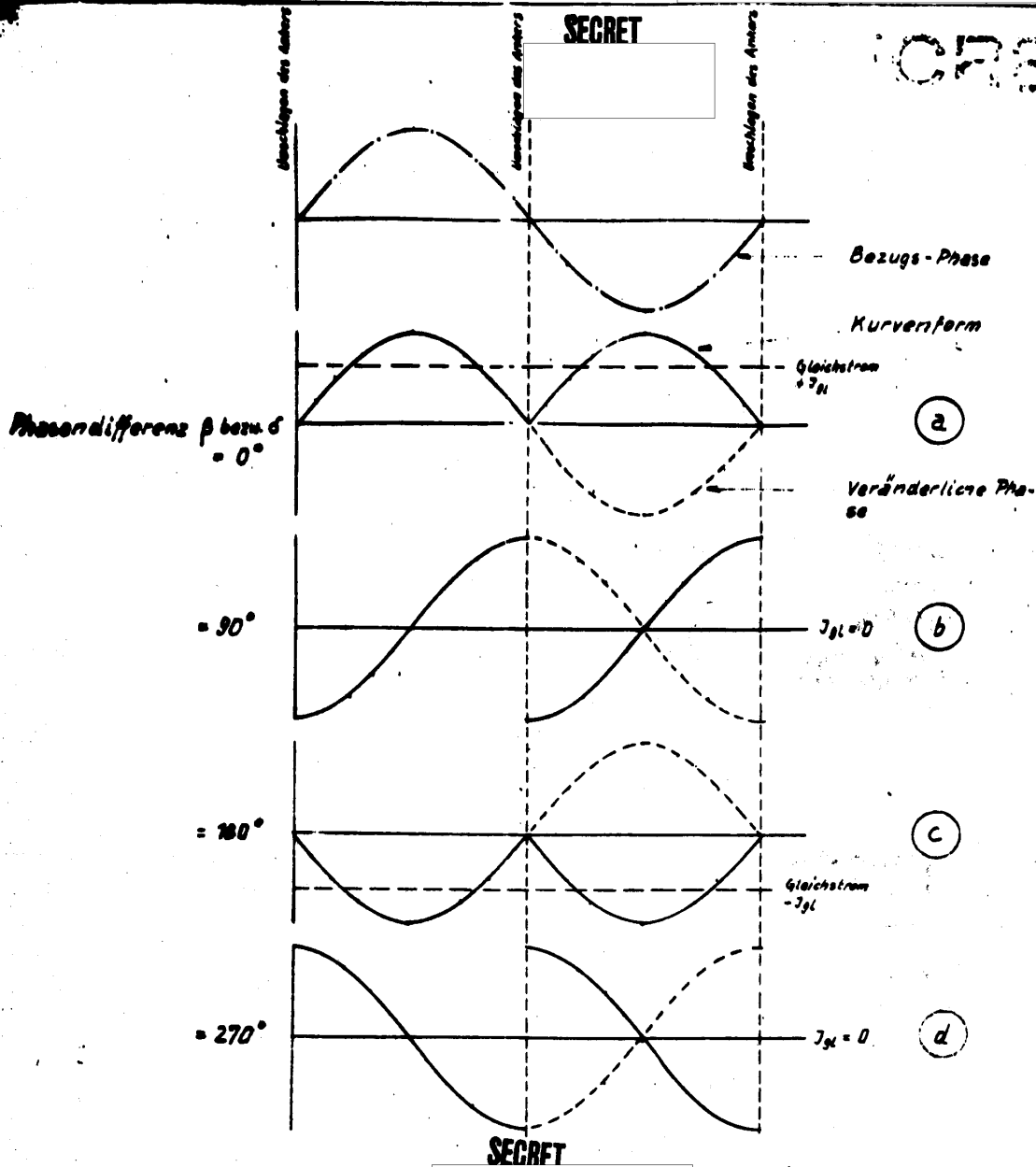


Abb. 23 Kurvenformen im Phasenkommutator (Strom in der Leitung a bzw. b)

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Annex P.

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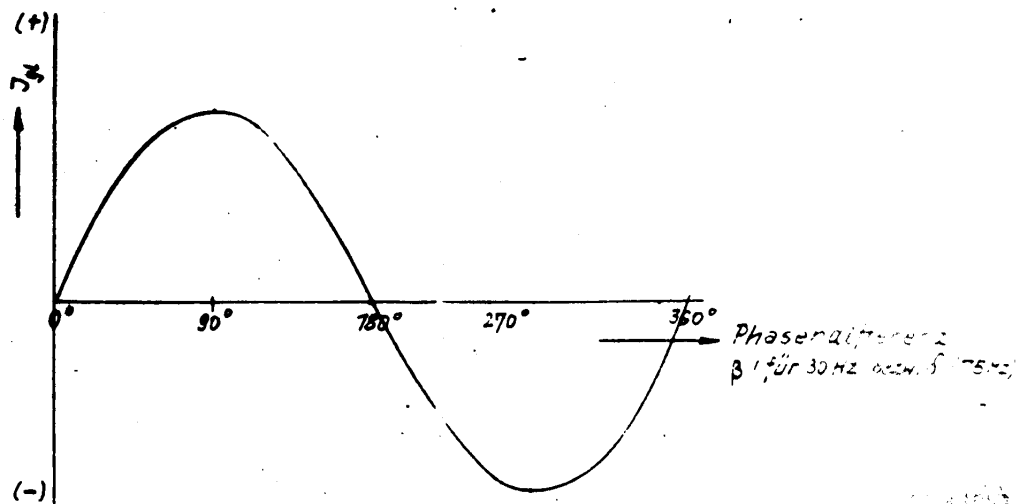


Abb.24 Gleichstrom als Funktion der Phasen-
differenz.

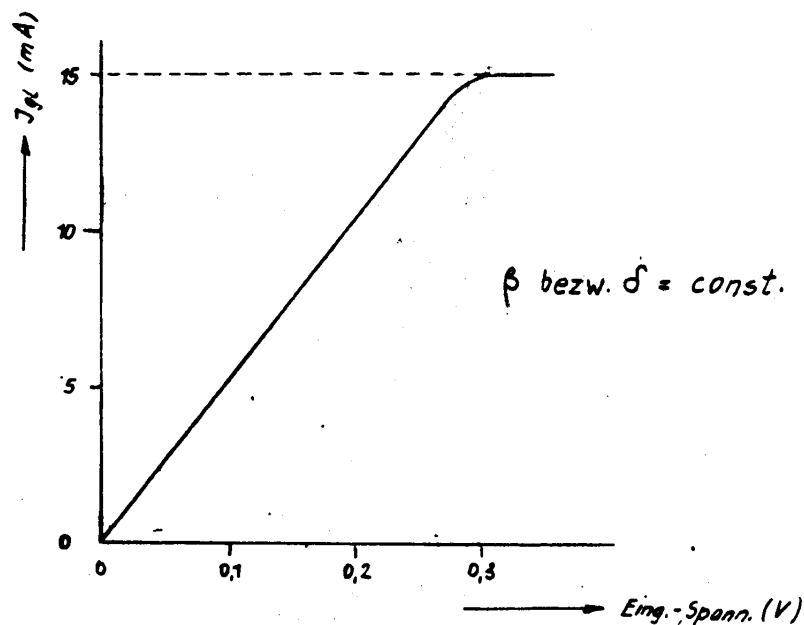


Abb.25 Gleichstrom als Funktion der Amplitude
der Eingangs-Spannung.

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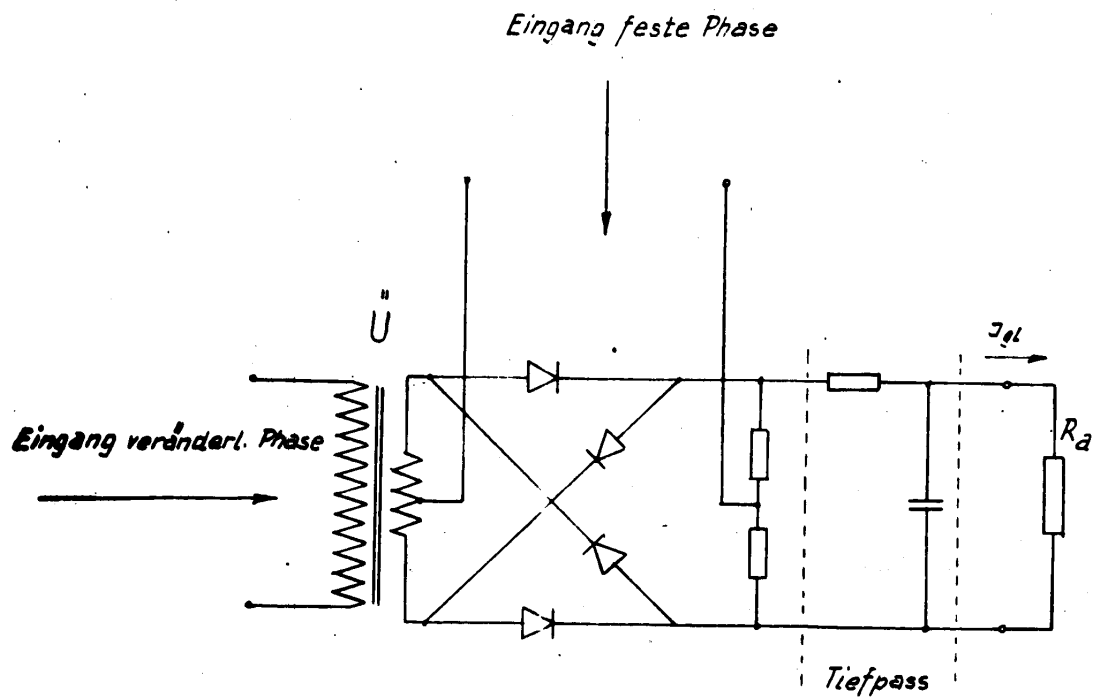


Abb. 26 Phasenkommutator mit Ringmodulator
(Prinzip-Stromlauf)

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